be placed in the same genus with *G.? ortmanni.* In sculpture it suggests the carinated forms that White has very doubtfully referred to *Lioplax endlichi* from the Bear River formation.

Locality.—Wettacombe's ranch, near Musselshell River, in the vicinity of Harlowton, Montana.

Horizon.—Upper part of Lower Cretaceous or base of Upper Cretaceous.

Explanation of Plate.

Unio farri Stanton.

Fig. 1. Right valve of type.

Fig. 2. Right valve of compressed form, probably male.

Unio douglassi Stanton.

Fig. 3. Left valve of a small specimen.

Fig. 4. Dorsal view of an average-sized specimen.

Viviparus montanaensis Stanton.

Fig. 5. Aperture view of the type, enlarged.

Goniobasis ? silberlingi Stanton.

Fig. 6. Aperture view of the type, enlarged.

Goniobasis ? ortmanni Stanton.

Fig. 7. Aperture view of fragmentary specimen with strong sculpture, enlarged. Outer lip restored from another specimen.

Fig. 8. Dorsal view of a similar specimen, enlarged.

Fig. 9. A specimen with only two spiral lines on the spire, enlarged.

Fig. 10. Aperture view of a specimen without spiral sculpture except on back of last whorl, enlarged.

Campeloma harlowtonensis Stanton.

Fig. 11. Aperture view of the type.

Fig. 12. Similar view of a broader, more umbilicated specimen.

REACTION AS AN EFFICIENT AGENT IN PROCURING DEEPER NAVIGABLE CHANNELS IN THE IMPROVEMENT OF RIVERS AND HARBORS.

BY LEWIS M. HAUPT, A.M., C.E.

(Read April 2, 1903.)

Consumption, production and distribution are the three main elements of trade. Without great facilities for distribution it is not possible to maintain a nice adjustment between supply and demand. One section of the earth may be starving, while another may be burning its excess of food for lack of cheap transportation.

The question, therefore, has its humane as well as its financial and scientific aspects. It is the aim of the engineer and the capitalist to reduce the cost of transportation to a minimum for the general welfare of mankind.

The great improvements which have been effected in the railways of the world have resulted in a rapid reduction in the average rates of freight, which are still falling. Roadmakers have caught the infection and are mending their ways as rapidly as the means become available. Sailing vessels are transformed into the schooner type of greater dimensions and are designed to be handled by smaller crews, so that it may be said they represent the cheapest class of carriers. The steamer also is being greatly enlarged in its capacity with the same end in view, but it has not and cannot reach the limit of its economic possibilities because of the absence of adequate channels at its terminals.

These great evolutions in transportation have been made possible in the United States by the concentration of mind, money and materials, working in harmony and resulting in a system of overland movements which is without a rival. It is the outgrowth of private capital, employed to develop limited areas, but gradually consolidated into trunk lines, and which finally, assisted by the National Government, united the two oceans. The merging of these great interests still continues and the end is not yet. These bands of steel have enabled our excess of production to reach the seaboard and be distributed to foreign markets, and it may not be out of order to glance very briefly at the magnitude of this movement.

Thanks to a beneficent Providence and the industry and intelligence of our people, our exports exceed our imports by an amount greater than that of all other nations. Their increase within a generation is startling. While the population has doubled in the past thirty years, the per capita of money has increased from $17.50 to $28.66.[1] The number of artisans has increased 2.7 times, while his average earnings have risen from $387 to $500 per capita per annum. The capital employed has expanded fivefold and the value of the output more than threefold. In consequence the per capita of our exports has increased in this same period from $7.29 to $18.81, of which the largest part is food-stuffs.

The increase in agricultural exports was over 300 per cent., and that of manufactures 750 per cent., so that this country heads the

[1] O. P. Austin, Chief of the Bureau of Statistics, in *The World's Work.*

list of exporting nations, having reached nearly one and a half billion dollars in 1901. The United States produces more wheat than any other country of the world; more corn than all other countries combined; more beef and pork than any other; three-fourths of the world's supply of cotton; of coal our exports exceed those of any other nation, and at far less cost. We are the mainstay of the world for petroleum for light, heat and other purposes, and we lead in the quantity and value of manufactured articles.[1]

For the internal distribution of the nearly 900,000,000 tons of traffic, resulting from our splendid resources and energies, we have over 200,000 miles of railways, or more than two-fifths of the world's mileage, to say nothing of the superior facilities for the distribution of thought by mail, telephone and telegraph. Thus it is seen that, although the population of the country has doubled within thirty years, the productivity of the nation has far exceeded this ratio, and that it is the main reliance of Europe for many of its necessities. Our importance as a base of supplies for the Orient is also rapidly increasing, and it is reasonable to suppose that the next generation will realize even greater developments than this.

The present year heralds the preparation which the great masters of transportation are making for "round-the-world" lines by the consolidation of the ocean carriers into the International Mercantile Marine Company, so that our exports may be delivered in vessels under domestic control at less cost, and our heavy freight bills to foreign flags be reduced. This is as it should be, and every possible encouragement should be given to all legitimate efforts to increase the circulation of material products and to reduce the cost, thus extending the market-range. But the mere multiplication in the number of vessels does not lower the cost unless it develops a keen competition between rivals. This competition is to some extent neutralized by combination, but under good management this effect may be more than offset by the reduction in fixed charges and by the use of vessels of greater tonnage, which can be operated at less cost per ton of cargo transported.

This brings us directly to the crux of the argument, for the vessels, having already outgrown their channels are obliged to await favorable conditions, clear with partial cargoes or lighter; in every case adding to the cost at the expense of the consumer, or restricting deliveries. It has been predicted that ere long vessels of 1000

[1] O. P. Austin, Statistician, Treasury Department, Washington.

feet length and forty or more feet draft would be upon us, but this economic ideal cannot be realized until some better method is developed for the creation and maintenance of much deeper channels. To meet this demand for deeper water more powerful dredges are building, in the hope of combatting successfully with the ceaseless activities of the bar-building elements, by sporadic mechanical devices, costing large sums to operate and offering serious obstacles to navigation by their presence in narrow channels. With the exception of Port Royal, with twenty-one feet; Gedney's Channel, with twenty-three feet; the Golden Gate, with thirty-two feet, and the Columbia Bar, with nineteen feet, the natural depth of scour over our alluvial bars seldom exceeds fifteen feet, and is more frequently limited to from three to twelve; while a modern vessel, fully laden, may draw thirty-two, and should have a channel depth of from thirty-five to forty feet for safe passage over a rough bar at low water. Hence the urgent demands made upon the national treasury for larger appropriations, that at least the most important of our railroad and commercial terminals may utilize these economies in transportation.

For the forty-four years prior to 1866, when our commerce was carried in much lighter-draft vessels, the total expenditure for waterway improvements was but $14,990,170; but between 1867 and 1901 they expanded to $332,487,627—making a grand total to that date of $347,477,897, to which should be added the appropriations of the last Congress of about $60,000,000 more, thus swelling the aggregate to over $400,000,000. In reporting the last bill the Chairman of the River and Harbor Committee stated that "the total amount which would be required for the completion of projects for river and harbor works . . . now considerably exceeds $300,000,000." If but ten per cent. of this sum can be secured annually it is evident that our commerce must "drag its slow length along" for many years, while the increase in the demand for greater facilities cannot be met unless greater efficiency may be secured in the methods in vogue.

During the score of years succeeding 1867 the average expenditures were $4,480,000, but soon thereafter, when deeper channels were demanded and the use of the submerged and twin jetties supplemented by dredging became the main reliance, the annual average reached nearly $13,000,000, with a rapidly increasing ratio. In the past quarter century the estimates and expenditures at only eight of our most important seaports, where jetties have been built or proposed for channels of modern depth, foot up to $50,515,784, but the difficulty of securing the depth has necessitated in such cases a resort to dredging to create and maintain the channel. These new conditions have resulted in the construction of powerful sea-going hydraulic dredges with great capacity, and have in a measure revolutionized the practice of deepening by scour, as it is considered by some more economical to use the dredge without regulating works. In consequence it is found that the amounts expended and estimated to complete the approved projects at only four of our principal ports by dredging alone will aggregate $41,396,129, exclusive of the large additional sums required for maintenance.

In view, therefore, of the important interests involved, the unreliability of dredged channels, the inadequacy of twin jetties and the great cost, it would seem pertinent to inquire whether the profession of engineering has reached its ultimatum in this department of science. Is it not possible to utilize to greater extent the boundless resources of nature for the purpose of creating deeper channels at our ports?

The magnitude of these forces will be better understood when it is shown that the sun as a prime mover evaporates approximately 15,000 tons from each square mile of the ocean's surface every twenty-four hours, so that his daily work upon the 150,000,000 miles of water surface represents a load of two and a quarter trillion tons, a large portion of which is carried by the wind-driven clouds to the land where it is recondensed. Assuming the precipitation to be proportional to the ratio of land to water, there would be 562 billion tons falling on the land surface, and taking the run-off at but 40 per cent., there results 225 billion tons of stored energy flowing down to the sea every day of the year, or, reducing this weight to its volumetric equivalent, we have nearly fifty cubic miles or 264,000 square miles of water one foot deep, an area greater than the State of Texas.

This is the fluid solvent which, in the laboratory of nature, is daily applied to earth-sculpture, while the portion at work in the chemical and metallurgical laboratories of the interior is much greater than this. The former is all that is available for the avenues of domestic commerce, while the latter is the part which contributes to its tonnage by developing its products.

For the foreign commerce there is the illimitable ocean with its dynamics—the tides, winds and currents—which are not yet fully understood nor utilized.

The poet Milton has aptly said :

> " Accuse not Nature, she hath done her part;
> Do thou but thine."

This prompts the question, How? It is to answer this query that attention will be briefly directed.

It is well known that engineering, like many other sciences, is largely empirical, and that more is learned from failures than from successes, for failures are the buoys which mark the channel to success. It becomes important, therefore, to review the experiences of the past, in which this country is particularly rich, that their lessons may guide us in preparing to satisfy the demands of the future. With this end in mind, a brief review will be made of a few types of harbor improvements, showing their physical features and results, and the methods which have produced them.

Existing Methods.

The devices in use to-day for the alleviation of the evils of ocean bars are twin jetties, dredging and dynamite, either singly or combined. The theory of the two-jetty system has been so long and ably discussed that little need be added further than to state that it is based upon the idea of preventing a dispersion of the currents by the building up of parallel or convergent training walls to concentrate the discharge upon a single path across the bar.

The objections to this system are that, being built out from shore, the confined waters are projected upon the inner slope of the bar, which is pressed seaward as they advance. Moreover, being at a fixed distance apart, they cannot be adapted to great ranges of stage, for if adjusted to a normal low-water discharge they will be too close to pass the floods without retardation, or the reverse. In any case there must result a sedimentation above, within or beyond the works, as will be shown later, and dredging must be applied for relief, and, furthermore, they reduce the tidal influx. Until within a few years twin jetties aided by dredging have been the panacea for all classes of harbor bars, regardless of the relations between deposits, discharge and the many other conditions affecting their formation and maintenance. It is important that a careful diagnosis be made of each case to ascertain its preponderating element.

Physical Considerations.

Thus it is seen that the physical agencies become of fundamental importance, and that a clear distinction must be made between bars formed from littoral drift and those formed from the detrītus carried down by streams. For tidal inlets it is also important to ascertain the prevailing direction of the littoral movements which have frequently but erroneously been supposed to follow the prevailing winds, whereas it is more frequently found to be the resultant of the configuration of the adjacent coast line and of the angular wave movements, especially during the flood tide, when the waves are most heavily charged with silt.

Knowing the direction of this general resultant, the engineer can then determine on which side of the channel his protecting work should be placed, although there still seems to be a radical difference of opinion as to whether it should be on the near or far side, for only recently it was recommended that if a single jetty were built at a certain inlet on the Southern coast, it should "be located on the south of the channel, since the drifting sands come from the north. At this place, however, while the drift is comparatively slow, it is an enormous sand bank which moves, and which always moves very positively in one direction, and it is difficult to see how such a constant force from the north could avoid crowding the channel close to the jetty." The jetty plan was therefore rejected. Frequent experience in the construction of two jetties, where the farther one has been built in advance of the nearer one, has served to show the fallacy of this location and order of procedure.

The requirements to be met at tidal inlets are, free admission of the flood tide as the only source of ebb energy, protection of the bar channel from the prevailing direction of the littoral drift, conservation of ebb tide as it passes seaward over a narrower path on the bar, development of its potential energy in useful work locally on the bar crest and an automatic adjustment to any stages of wind or tide. All of these may be better fulfilled generally by one jetty than by two, and manifestly at about half the cost. These results are rendered possible by placing in the way of the ebb current a curved resisting medium in such position as to maintain a continuous reaction along its concave face. In fine, this structure becomes the tool for the conversion of the effluent energy into useful work, with lateral transportation of the eroded material.

Reaction versus Velocity.

The opinion is prevalent that the deep pockets frequently observed at the ends of spurs or obstacles or at contractions in rivers are due to velocity, and it has been stated that because a mean ebb velocity of two feet per second maintains a depth of over 100 feet at the Narrows of New York Harbor, therefore a similar contraction on the bar near Sandy Hook would produce some such depths. This was made the basis in 1886 for a proposition to build a jetty nearly five miles long, closing three of the channels across the New York bar. The great depth at the Narrows is not a velocity but a reaction depth, due to the resistance which the converging shores oppose to the passage of the flood, not the ebb tide, which increases the head before reaching the pass, depressing the resultant to the bottom, from which it reacts and scours out a depth to compensate for the lateral contraction. At other points in the harbor velocities of more than two feet per second do not scour to depths exceeding three feet, so that the results must be ascribed to some other cause than mere velocity.

An extended investigation of these abnormal depths leads to the conclusion that they are caused by eddies operating in a vertical plane, these eddies being caused by obstacles placed in the path of a current in such manner as to retard the flow by the interference due to converging forces, thus creating a head with a downward resultant and scour until compensation is secured by enlarged aperture. Here the reaction produces a change of direction of the resultant, which is deflected upward with dispersion of energy, deposit of material and ultimately restored equilibrium. These facts are doubtless well known to many observers, but the particular point to which attention is directed in this connection is that the downward movement producing scour is supplemented necessarily by the upward resultant, accompanied by deposit in the same vertical plane, so that whichever way the eddy operates, whether with flood or ebb, the bar is a sequence of the pocket, unless other forces come to the rescue. Thus it appears that an eddy both scours and deposits. These effects are reciprocal results of the same eddy, and not of two separate ones. But eddies also operate in horizontal planes, and with like results. When the obstacle is limited in extent the effect is local, but when the resistance is maintained the reaction continues to be developed and the energy to be expended until the resistance ceases.

The great advantages resulting from a continous reaction produced by a concave directrix appears to have been largely ignored in the work of river and harbor improvement, and yet the location of the best channels under the concave banks of rivers attests its value to commerce. It is true that numerous curved dikes and revetments have been placed in the concave bends of rivers, but the object has been to protect them *from* erosion and not to encourage it. Their value as tools to cut away an ocean bar does not appear to be fully appreciated, since where single curved jetties have been built the convex face has generally been turned to the current, to encourage, as has been said, the tendency which water has to follow a convex curve. (?)

The concave directrix has also the great advantage of maintaining the head due to centrifugal force and thus changing the direction of the resultant downwardly, producing the lateral scour and resulting convex bank or counterscarp created by the stream acting as an hydraulic auger, and of automatically adjusting this counterpart to the variable requirements of its regimen.

These general principles will be more fully elucidated by illustrations selected from surveys and models, showing the holes bored by reaction and the shifting of channels by artificial works, which are instructive as to the intimate relation between cause and effect.

A study of the natural effects found to exist under certain conditions enables the engineer to predict with some assurance the results which may follow a utilization of the available forces at any site. One of the most instructive examples of the vertical eddy is to be seen in the Narrows at New York, to which reference has already been made. Here the bottom currents are with the flood tide for about eleven hours out of the twelve, and this resultant flood extends as far up as the Battery. The ebb resultants are greatest at the surface and diminish rapidly with the depth, reaching their point of reversion at or near forty feet in the Narrows. On the bar the ebb currents show a feeble resultant at a depth of less than twenty-four feet in but one of the channels.

The remarkable "slue" which has maintained its position athwart the path of the currents since the earliest surveys has excited some attention as to its phenomenal position and depth of fifty-two feet.

It is referred to in the early Coast Survey Reports, and was made the subject of a special paper by the late honored member of this Society, Prof. Henry Mitchell, who prepared a manuscript report upon it, in connection with the physics of the lower bay, in 1858, but which was not published. It serves to confirm the claims of this paper that depths may be and frequently are the result of eddying action rather than velocity. The confluence of three currents produces a resultant having a northeasterly set which impinges upon the bar at the head of Gedney's Channel and is deflected thence by this resisting bank of sand northwardly, boring out the slue for a length of a mile and a width of a half mile. The latest survey shows a depth of fifty-three feet, with but eighteen feet on either flank. It was proposed at one time to change the direction of this resultant by cutting off one of its components and training the currents seaward to open Gedney's Channel by the utilization of this force, but it was not accepted. Again, the reaction at the head of Sandy Hook has produced a maximum depth of sixty-eight feet, diminishing within about a mile to thirty feet, while abreast of the point and a half mile distant the depth is but sixteen feet.

The construction of the old Breakwater at the mouth of the Delaware in 1828 furnishes some instructive lessons as to the changes effected by obstacles placed in a tideway. Here, at the ends of the ice-breaker and of the breakwater, are to be found the characteristic deep holes resulting from the head generated by the resisting structures. At the gap the pockets are on the outside of the opening, and the depths are the effects of the flood-tide. Both of these pockets are fifty feet deep, and the material scoured out from them has been carried into the harbor and deposited in the lee of the structures, making a shoal with only ten feet at one point. At the southeastern end of the breakwater the ebb reaction has scoured to a depth of fifty-four feet, while at the western end of the ice breaker the hole is due to the flood, and is limited to about forty feet. Moreover, the diagrams of velocity curves show that in the centre of the harbor, where the maximum velocity of the ebb is six feet per second, the bottom has not been prevented from shoaling to about fifteen feet, while a similar ebb velocity at the "gorge" is able to maintain depths of thirty feet. If these depths are due solely to velocities they should be equal, since like causes should produce like effects.

Numerous other instances of these abnormal depths due to reaction, and not to velocity simply, might be cited, but a few must suffice.

In the Thoroughfare at Longport, N. J., the landing pier has caused a hole forty-eight feet deep, while 800 feet away there was a bar bare at low water, but covered by a tidal current almost as swift as that past the pier.

In the Charleston gorge the maximum depth was eighty-two feet, while on the bar seaward thereof the depth was zero, and the best crossing was six miles south of the gorge. At Fernandina (Cumberland Sound), Ga., the maximum depth at the head of Amelia Island, projecting into the channel, was sixty feet, and abreast of it bare at low water.

The Galveston gorge shows about fifty-eight feet, while the normal bar depths were twelve to thirteen. The St. John's river, Fla., swings to the sea through a radius of one mile, carrying a maximum depth of fifty and three-tenths feet, and as the axis straightens to a tangent the depth diminishes to twenty feet. It then strikes a jetty at an abrupt angle which develops its latent energy and scours to fifty and two-tenths feet, but as this is not maintained by the convex curve of the jetty, the channel deteriorates to about eleven feet.

The building of a spur in the Mississippi river at right angles to the bank had the effect of increasing the depth from twelve to nearly one hundred feet in consequence of the violent eddy which was created, and now that the spur is covered and the river has assumed a new regimen, the depth has shoaled to about thirty feet, which is maintained.

From these few instances it would seem to be a fair inference that depths may be developed quite as well by single lines of concave directing works as by two, if proper attention is given to the volume of affluent as well as to the relative amount and direction of the motion of the bar-building materials.

Practical Suggestions.

In view of the requirements as previously stated, it is evident that to protect the proposed channel from the littoral drift a submerged low-tide or half-tide jetty will not suffice to arrest this drift, but it should extend above the highest tide. It must also be placed between the channel and the source of the prevailing drift, just as a snow- or a sand-fence must be placed to "windward" to protect a rail- or wagon-way.

It must be curved, concave to the effluent currents, to develop a continuous reaction, and should be constructed inward from the outward slope of the bar, to avoid the advance of the crest and to utilize the force of gravity in cutting shoreward and downward, instead of seaward and upward. These are some of the conditions which give promise of the greatest results attainable at a given location. Taking now a few typical illustrations of the several methods in vogue, it is seen that the New York entrance is to be deepened by dredging some 42,000,000 cubic yards from the bar, beginning at the easterly end of Ambrose Channel, at a cost of about $4,000,000, but with no definite time limit.

Although this sector of the bar shows a remarkable degree of permanency, it can hardly be expected that the formation of this deep cut, created by artificial means in the open sea, at a point where the natural depths are steadily maintained at from sixteen to eighteen feet, will long remain open. If it be assumed that normal conditions would be restored, say, in a period of ten years, it would represent an annual accretion of about 4,000,000 cubic yards to be removed by dredging, which at the present price would cost $360,-000, or the interest at three per cent. on $12,000,000. For a much smaller sum it would be possible to train the currents through this new and shorter channel by permanent works which would maintain it and at the same time become a valuable aid to navigation.

The effects of the submerged jetty type is best seen at Charleston, where the littoral drift is southward. Here the outer ends of the jetties are raised above high water, but the shore flanks are far below the surface, to admit the tides freely. The result is that the beach sand travels across them and forms shoals within the harbor, while it also travels around the outer end and maintains a bar in the open sea more than half a mile beyond the works, through which the channel must be maintained by dredging.

At Galveston, where the submerged plan was modified to reach above high water, the building out of the south jetty first has caused the bar to advance some three miles, adding that length to each of the jetties, which are 7000 feet apart, and a new bar is forming across the mouth in the lee of the north jetty. The channel must also be maintained by dredging.

At the mouth of a sedimentary river, like the Mississippi, where the silt comes from within, two jetties give much greater promise of success, and the great work of Captain James B. Eads in opening the South Pass by parallel jetties curving to the westward has proven to be a boon to the country. These jetties were built under adverse conditions, as payments were conditioned upon results to be secured, and as the first pair of jetties did not suffice to give the requisite depth, it became necessary to build spurs, then a second line of works, and finally a second series of spurs before the legal depths were obtained. This, however, resulted in an over-contraction of that outlet, and has caused the retarded currents to drop their sediment in the Pass above the jetties instead of beyond them, involving dredging.

Probably the most successful work of this kind at a river's mouth is that completed at the mouth of the Panuca river, Tampico, Mexico, where in two years' time two parallel straight jetties were constructed about a mile and a quarter long across a bar, having depths varying from five to twelve feet, and as soon as they were finished a severe flood flushed the channel so completely that the depths of twenty-seven feet have remained ever since, the littoral current here being sufficiently strong to remove the sediment carried out beyond the jetties. The engineer of this work was E. L. Costhell, C.E.

At Aransas Pass, a purely tidal inlet on the Texas coast, a single reaction breakwater, in an incomplete condition, has produced a progressive deepening by the control of feeble tides, unaided by dredging, and at a cost of less than one-third that of the estimated project, thus fully demonstrating the great practical utility of the single reaction jetty system at the only point where an opportunity has been afforded for a test on a large scale in this country, after about fifteen years of persistent effort The Consulting Engineers of this work were Messrs. H. C. Ripley, Geo. Y. Wisner, and the writer.